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DRAG AND STABILITY DATA OBTAINED FROM FREE-FLIGHT HYPERSONIC FIRINGS OF BOTH SHARP AND BLUNT NOSED 12-DEGREE 40-MINUTE TOTAL-ANGLE CONES AT SEVERAL RANGE PRESSURES

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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DRAG AND STABILITY DATA OBTAINED FROM FREE-FLIGHT HYPERSONIC FIRINGS OF BOTH SHARP AND BLUNT NOSED 12-DEGREE 40-MINUTE TOTAL-ANGLE CONES AT SEVERAL RANGE PRESSURES

Prepared by:
Leonard E. Crogan

ABSTRACT: Drag and stability data obtained from hypersonic firings of both pointed and blunt nosed 12-degree 40-minute total-angle cones at several range pressures are tabulated. The drag coefficient of both cones decreased with an increase in the Reynolds number. No effect of Reynolds number on the center of pressure of either cone configuration was observed.

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This report presents the results of firings made with 12-degree 40-minute total-angle cones to determine their free-flight characteristics at hypersonic velocities and at several range pressures. The firings were conducted in the Pressurized Ballistics Range at the Naval Ordnance Laboratory.

J. A. DARE
Captain, USN
Commander

A. E. Seigel
A. E. SEIGEL
By direction

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ILLUSTRATIONS

TABLES

REFERENCE

(1) Murphy, C. H., "Data Reduction for the Free-Flight Spark Ranges," BRL Report No. 900 (1954)

LIST OF SYMBOLS

$C_D = \frac{D_t}{qS}$	total-drag coefficient based on the maximum body cross-sectional area (S) of the model
C_{M_α}	(slope of the pitching moment)/qSD = slope of the pitching-moment coefficient referred to the CG of the model
$C_{M_q} + C_{M_{\dot\alpha}}$	$\frac{\text{(slope of yaw-damping moment due to q)}}{\frac{D}{2V}\ qSD} + \frac{\text{(slope of yaw-damping moment due to }\dot\alpha)}{\frac{D}{2V}\ qSD} =$ slope of damping-moment coefficient referred to the CG of the model
C_{n_α}	(slope of normal force)/qS = slope of normal-force coefficient
Cal.	Caliber = one maximum diameter of model
CG	center of gravity
CP	center of pressure
D	maximum diameter of model
D_t	component of the aerodynamic force directed along the trajectory
I_β	transverse moment of inertia about CG of model
k_D, k_M, k_N	parameters used to correct to zero yaw the drag, pitching-moment, and normal-force coefficients, respectively
l	length of model
M	free-stream Mach number (usually based on midrange value of V)
P	free-stream range pressure
P.E.	probable error based on accuracy of data fitting (P. E.s, swerve equation· P. E. y, yaw equation)

$q = \frac{\rho V^2}{2}$	dynamic pressure; or q = lateral component of angular velocity of model
$Re_l = \frac{\rho V l}{\mu}$	Reynolds number based on length of model
$S = \frac{\pi D^2}{4}$	maximum cross-sectional area of model
V	velocity (usually a midrange value)
α	angle of attack
$\dot{\alpha}$	rate of change of angle of attack with time
$\overline{\delta^2}$	mean-squared yaw
μ	coefficient of viscosity
ρ	density of air

Subscripts

o	quantity corrected to zero yaw
B	quantity measured from base of model; or B designates transverse moment of inertia

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INTRODUCTION

Cone firings were conducted in the Pressurized Ballistics Range at the Naval Ordnance Laboratory to determine drag and stability characteristics at several Reynolds numbers and at a hypersonic velocity.

MODEL DETAILS

With the exception of one round, the cones were all one size as illustrated in figure 1. This one cone was round number 4339 and was twice the size of the other cones. Drag only was obtained from this round because of the insufficient number of stations for a stability reduction. The drag coefficient agreed favorably with those obtained with the smaller models. The physical dimensions of the cones are listed in Table I.

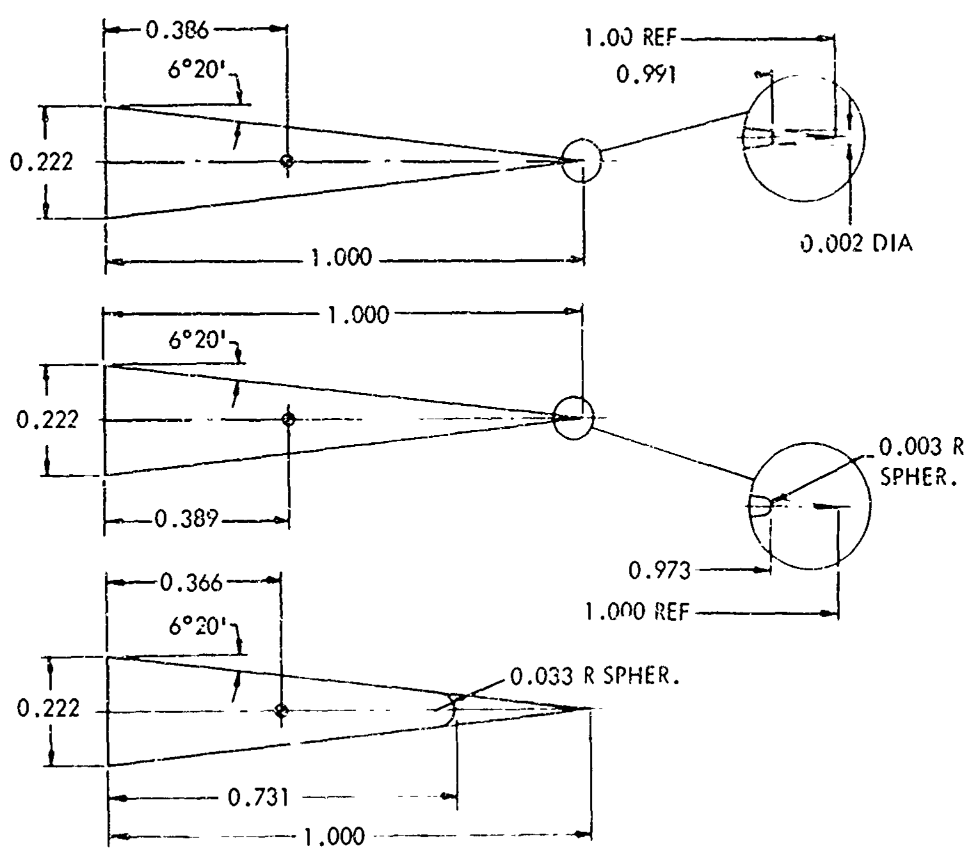


FIG. I CONE CONFIGURATIONS

TABLE I

PHYSICAL DIMENSIONS OF AERONUTRONICS CONES

Round No.	Base Dia. (in.)	Length (in.)	CG_B (in.)	Weight (gms.)	I_B (gm.-in.^{2})
		Pointed Cones			
4296	.222	.987	.387	1.4375	.068
4299	.223	.996	.390	1.4296	.068
4302	.223	.993	.390	1.4277	.067
4307	.223	.999	.386	1.4074	.067
4309	.222	.994	.395	1.4395	.068
4322	.223	1.004	.394	1.4500	.071
4323	.222	.998	.394	1.4126	.068
4335	.222	.989	.394	1.4422	.069
4336	.223	.994	.393	1.4080	.068
4337	.223	1.000	.395	1.4471	.070
4338	.222	.985	.389	1.4381	.067
4339	.452	2.000	.720	4.9660	1.029
4340	.223	.992	.390	1.4208	.067
4399	.224	.999	.400	1.4025	.070
4400	.223	1.002	.401	1.3626	.070
4401	.223	1.001	.400	1.4086	.071
4402	.224	1.001	.402	1.4040	.072
4404	.223	1.000	.400	1.4255	.073
4732	.221	.973	.406	1.5109	.052
		Blunt Cones			
4388	.225	.731	.369	1.3485	.056
4389	.224	.730	.370	1.3512	.056
4390	.224	.730	.370	1.3251	.055
4392	.224	.732	.374	1.3523	.056
4395	.224	.731	.370	1.3373	.055
4396	.225	.731	.370	1.3284	.055
4397	.224	.731	.370	1.3321	.055
4723	.222	.731	.373	1.1854	.050
4727	.222	.731	.370	1.1954	.050
4742	.222	.725	.351	1.4734	.063

Except for the rounds fired at atmospheric conditions, all cones had tungsten alloy noses which were silver soldered to hollow titanium alloy afterbodies. The cones launched at atmospheric conditions were manufactured with pure tungsten noses in order to alleviate the ablation problem which exists at atmospheric conditions and accompanying high Mach numbers. Figure 2 shows the pointed cone with its sabot used to launch it from a 1.25-inch single-stage light-gas gun.

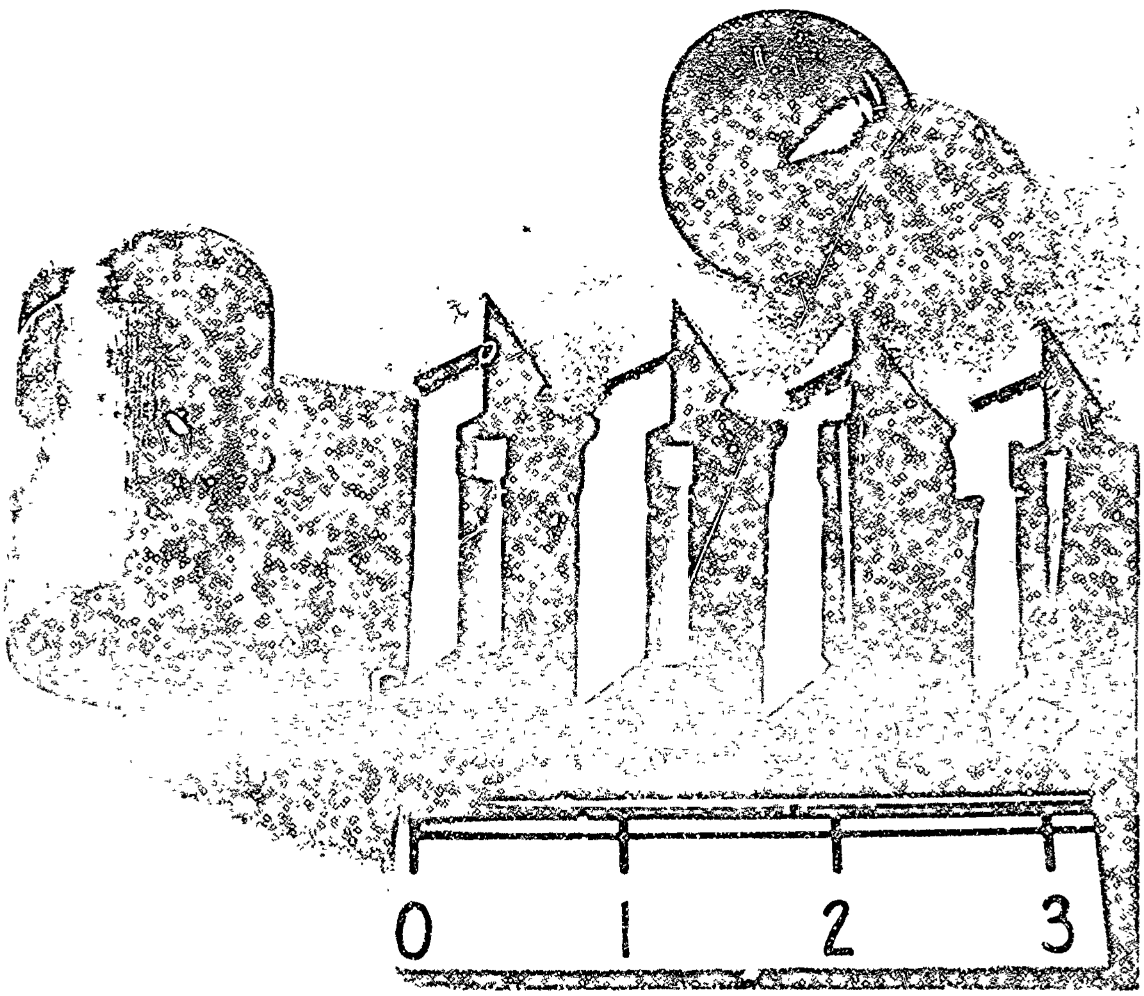


FIG. 2 POINTED CONE WITH ITS SABOT, BOTH ASSEMBLED AND EXPLODED

DISCUSSION AND RESULTS

The drag and stability coefficients were obtained using standard data reduction techniques as described in reference (1). Table II lists the drag and stability data obtained for the blunt cones, and Table III lists the data obtained for the pointed cones.

TABLE II

DRAG AND STABILITY DATA FOR 12° 40' TOTAL ANGLE BLUNT CONES

Round No.	4742	4723	4727	4388	4389	4390	4397	4396	4392	4395
P (mm Hg)	761.4	760.1	758.2	99.2	91.0	75.5	72.9	47.8	47.5	46.3
M	8.244	7.712	7.390	9.308	9.186	9.181	9.428	9.433	9.422	9.642
$R_{e_l} \times 10^{-6}$	3.354	3.181	3.013	0.500	0.453	0.374	0.372	0.244	0.242	[illegible]
$\overline{\delta^2}$ (deg.^{2})	34	40	48	33	25	130	49	38	30	[illegible]
C_D	0.1479	0.1594	0.1573	0.1661	0.1590	0.2421	0.1673	[illegible]	0.1674	[illegible]
±P. E.	0.0001	0.0002	0.0002	0.0005	0.0005	0.0004	0.0007	0.0009	0.0006	0.001
C_{D_0}	0.1246	0.1316	0.1247	0.1407	0.1395	0.1407	0.1448	0.1477	0.1442	0.145
P. E. yaw (± deg.)			2			0.5		0.3	0.2	
P. E. swerve (± in.)			0.02			0.01		0.007	0.006	
C_{N_α} deg.	-0.0080	-0.0119	-0.0122	-0.0101	-0.008	-0.0135	-0.009	-0.01244	-0.00910	
±P. E.	0.0004	0.0002	0.0001	0.0002	-	0.0002	-	0.00004	0.00004	
$C_{N_{\alpha_0}}$/deg.	-0.0065	-0.0101	-0.0100	-0.0086	-0.007	-0.0076	-0.008	-0.00811	-0.00773	
C_{M_α}/deg			-0.032			-0.036		-0.031	-0.020	
±P. E.			0.005			0.004		0.001	0.001	
$C_{M_{\alpha_0}}$/deg			-0.025			-0.019		-0.020	-0.016	
(CP-CG) cal.			0.396			0.377		0.388	0.454	
CG_B (cal.)			1.667			1.652		1.644	1.670	
CP_B (cal.)			1.271			1.275		[illegible]	[illegible]	
$(CP-CG)_0$ cal.			0.400			0.400		[illegible]	0.483	
CP_{B_0} (cal.)			1.267			1.252		[illegible]	[illegible]	
$C_{M_q} + C_{M_{\dot\alpha}}$			0					-6		
±P. E.			2					2		

TABLE III

DRAG AND STABILITY DATA FOR 12° 40' TOTAL ANGLE POINTED CONES

Round No.	4732	4337	4296	4357	4339	4302	4326	4322	4299	4338
P (mm Hg)	755.8	100.2	99.9	98.5	97.8	85.8	82.9	79.7	77.1	76.4
M	9.198	9.133	9.001	8.206	9.260	9.037	9.076	9.253	9.167	9.126
$R_{e_1} \times 10^{-6}$	4.984	0.686	0.657	0.605	1.401	0.579	0.557	0.549	0.527	0.515
$\overline{\delta^2}$ (deg.²)	2.1	3.4	85	17	20	20	55	174	19	59
C_D	0.05823	0.081	0.126	0.0910	0.087	0.0950	0.124	0.267	0.096	0.225
±P. E.	0.00009	0.004	0.001	0.0009	0.003	0.0005	0.008	0.007	0.002	0.001
C_{D_0}	-	0.079	0.079	0.0815	0.076	0.0817	0.087	-	0.089	0.085
P. E. yaw (± deg.)	0.3			0.3		0.5				0.4
P. E. swerve (± in.)	0.02			0.02						0.02
C_{M_α}/deg.	-0.0095	-0.010	-0.011	-0.00913		-0.0123	-0.008	-0.011		-0.00965
±P. E.	0.0001			0.00009		0.0002	0.002			0.00008
$C_{M_{\alpha_0}}$/deg.	-0.0095	-0.010	-0.016	-0.00896		-0.0121	-0.007	-0.009		-0.00927
C_{N_α}/deg.	-0.03			-0.036						-0.036
±P. E.	0.01			0.004						0.003
$C_{N_{\alpha_0}}$/deg.	-0.03			-0.035						-0.034
(CP-CG) cal.	0.300			0.256						0.272
CG_B (cal.)	1.837			1.731						1.752
CP_B (cal.)	1.537			1.475						1.480
$(CP-CG)_0$ cal.	0.317			0.256						0.273
CP_{B_0} (cal.)	1.520			1.475						1.475
$C_{M_q} + C_{M_{\dot\alpha}}$	-3			-16						-13
±P. E.	3			5						5

Round No.	4399	4323	4309	4401	4400	4335	4402	4404	4340	
P (mm Hg)	66.0	65.6	63.2	62.4	56.2	50.7	37.7	35.9	32.5	
M	8.971	8.662	9.336	9.038	9.131	9.135	9.198	9.104	8.968	
$R_{e_1} \times 10^{-6}$	0.437	0.323	0.439	0.413	0.377	0.363	0.255	0.238	0.218	
$\overline{\delta^2}$ (deg.²)	156	1366	71	48	115	89	53	114	640	
C_D	0.2208	1.364	0.15	0.1196	0.201	0.150	0.140	0.183	0.96	
±P. E.	0.0006	0.009	0.01	0.0004	0.001	0.004	0.001	0.064	0.02	
C_{D_0}	-	-	0.10	0.0862	-	0.096	0.103	0.103	-	
P. E. yaw (± deg.)	0.3	1.6		0.2	0.2		0.2			
P. E. swerve (± in.)	0.01			0.007	0.01		0.008			
C_{M_α}/deg.	-0.01156	-0.0134	-0.012	-0.01040	-0.01249	-0.011	-0.0117	-0.011	-0.014	
±P. E.	0.00002	0.0001		0.00003	0.00003		0.0001			
$C_{M_{\alpha_0}}$/deg	-0.01002	-	-0.011	-0.00992	-0.01132	-0.010	-0.0112	-0.010		
C_{N_α}/deg	-0.0369			-0.033	-0.037		-0.032			
±P. E.	0.0008			0.001	0.001		0.001			
$C_{N_{\alpha_0}}$/deg.	-0.0316			-0.031	-0.033		-0.030			
(CP-CG) cal	0.313			0.316	0.340		0.366			
CG_B (cal.)	1.786			1.794	1.798		1.795			
CP_B (cal.)	1.473			1.478	1.458		1.429			
$(CP-CG)_0$ cal	0.317			0.320	0.343		0.373			
CP_{B_0} (cal.)	1.469			1.474	1.455		1.422			
$C_{M_q} + C_{M_{\dot\alpha}}$	-8			-7	-7					
±P. E.	1			2	2					

The drag coefficients and the slopes of the pitching-moment and normal-force coefficients were corrected to zero yaw. The equations used are as follows:

$$C_{D_o} = C_D - k_D \overline{\delta^2}$$

$$C_{M_{\alpha_o}} = C_{M_\alpha} - k_M \overline{\delta^2}, \text{ and}$$

$$C_{N_{\alpha_o}} = C_{N_\alpha} - k_N \overline{\delta^2}$$

where the slope k_D was determined using data from a number of rounds launched at approximately the same conditions, and the slopes k_M and k_N were determined using all rounds regardless of pressure. No trend of the slope of the dynamic stability coefficient with mean-squared yaw could be observed, and therefore, this coefficient was not corrected to zero yaw.

Figure 3 is a plot of the zero-yaw drag coefficient as a function of Reynolds number. The plot shows a decrease in

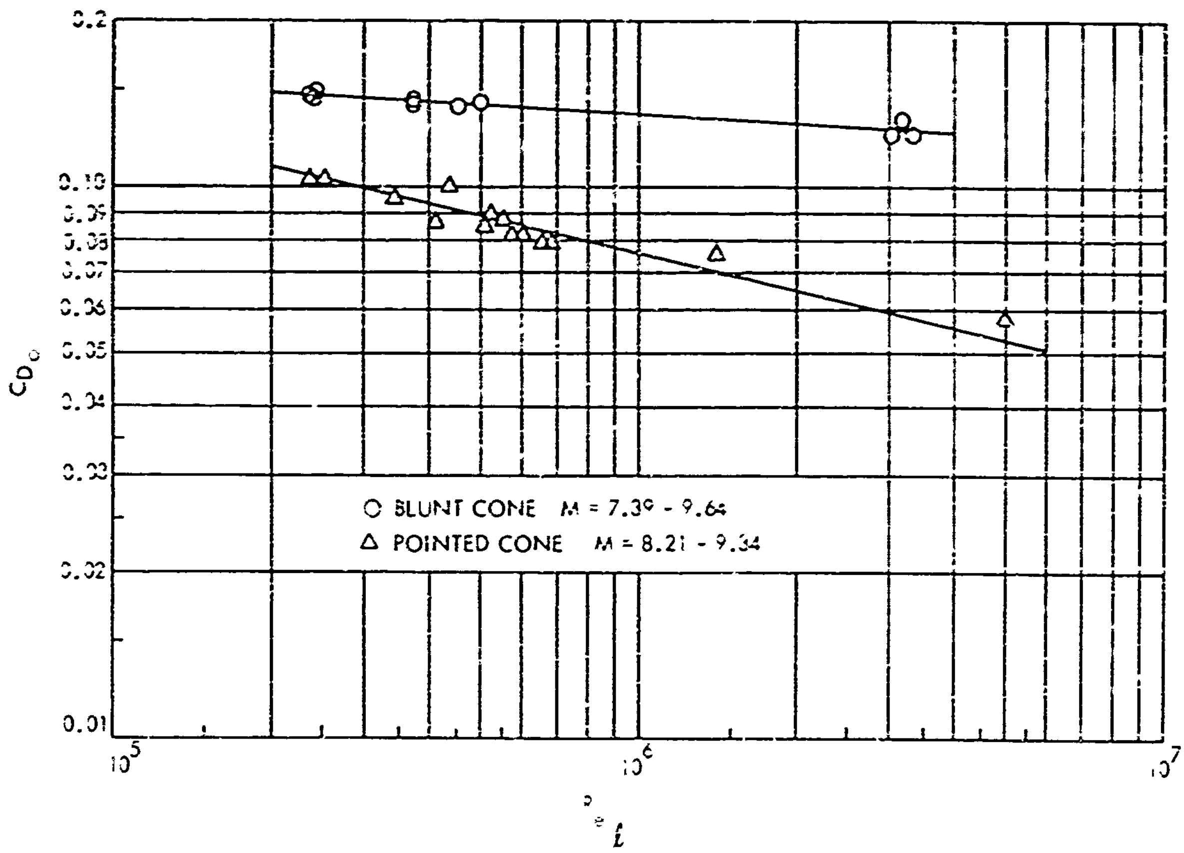


FIG. 3 ZERO YAW DRAG COEFFICIENT AS A FUNCTION OF REYNOLDS NUMBER

the drag coefficient with an increase in Reynolds number for both cones investigated at the Mach numbers at which the program was conducted. Within the probable error of the coefficient, no effect of Reynolds number on the slopes of the pitching-moment and normal-force coefficients was observed. Therefore, no movement of the center of pressure with varying Reynolds number occurred at the conditions investigated. These conditions were for laminar-boundary layer flow only. Figures 4, 5, and 6, respectively, show the slopes of the pitching-moment and normal-force coefficients and center of pressure as a function of Reynolds number.

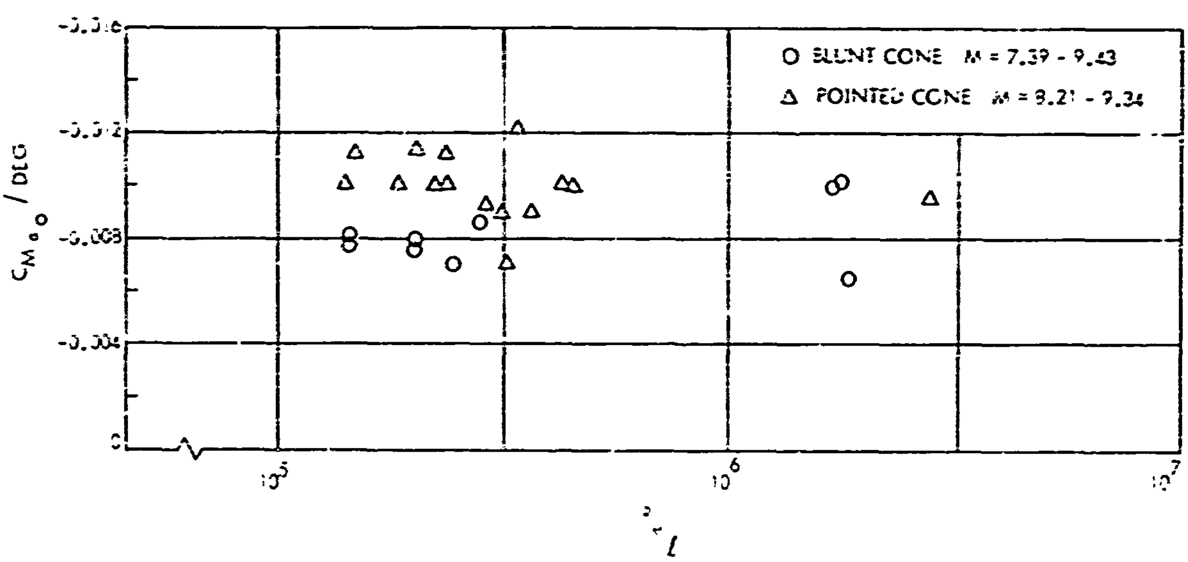


FIG. 4 SLOPE OF THE PITCHING MOMENT COEFFICIENT CORRECTED TO ZERO YAW AS A FUNCTION OF REYNOLDS NUMBER

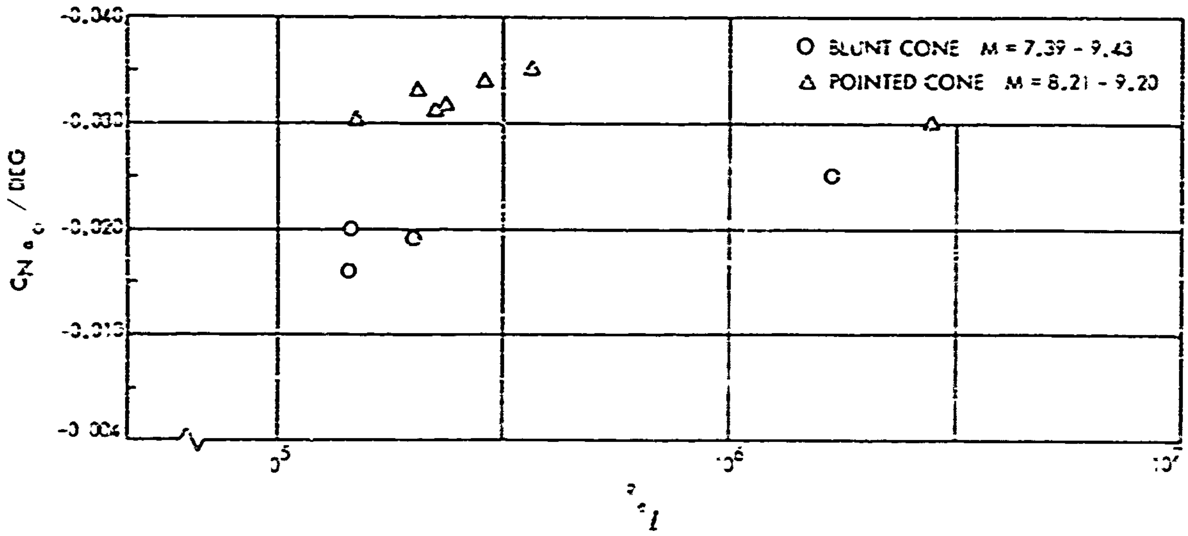


FIG. 5 SLOPE OF THE NORMAL FORCE COEFFICIENT CORRECTED TO ZERO YAW AS A FUNCTION OF REYNOLDS NUMBER

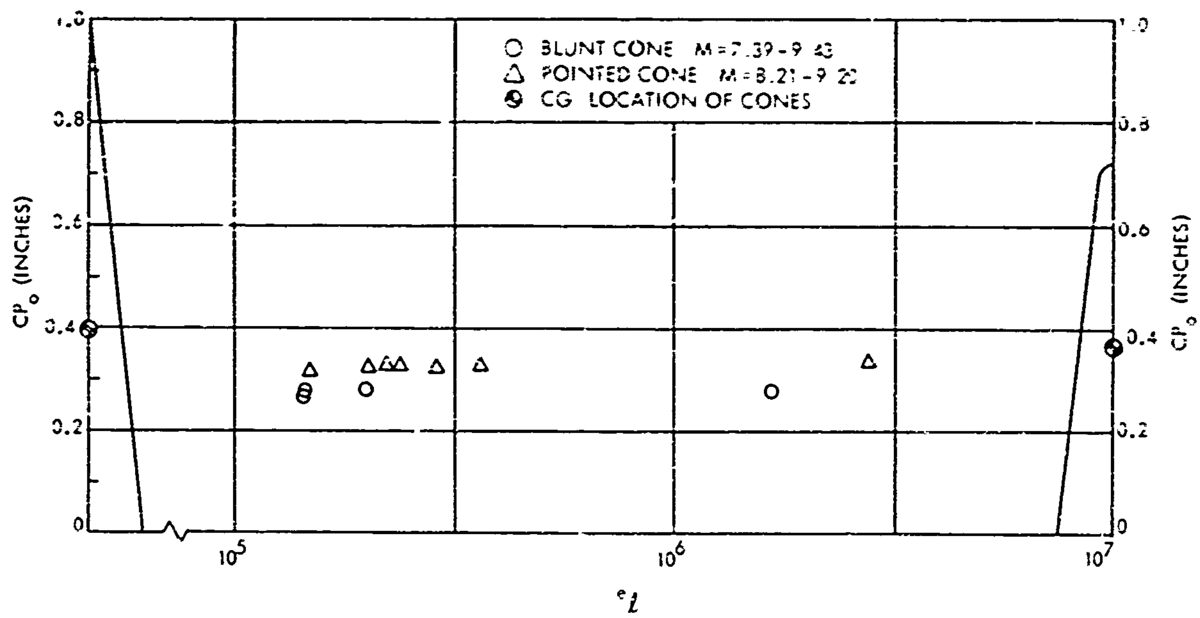
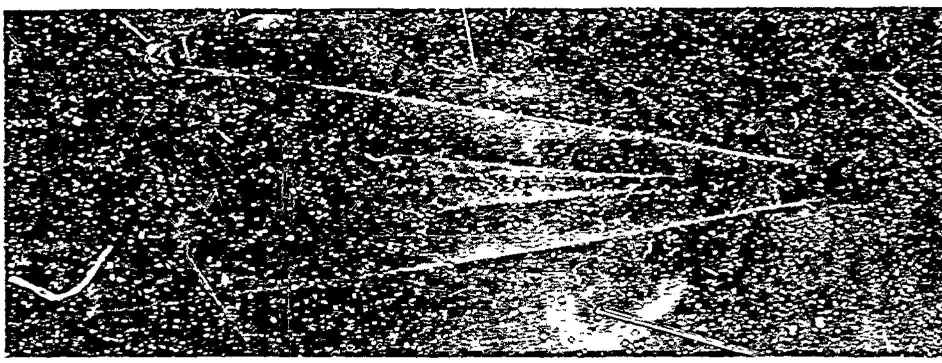


FIG 6 ZERO YAW CENTER OF PRESSURE LOCATION AS A FUNCTION OF REYNOLDS NUMBER

Figures 7(a) through 7(l) include a set of representative shadowgraph prints of both cone configurations at all of the pressures investigated.

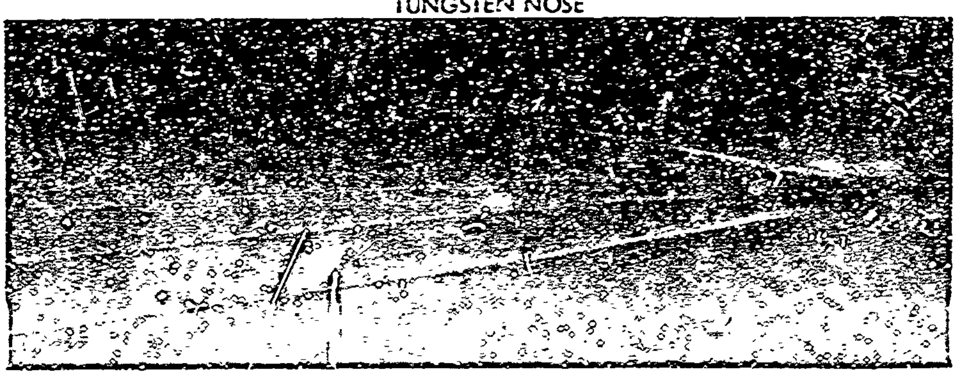


(a) SHOT NO. 4732, STATION 9V

$R_N / R_B = 0.027$, $M = 9.260$

$P = 1$ ATM, $R_{e_\ell} = 9.193 \times 10^6$

TUNGSTEN NOSE

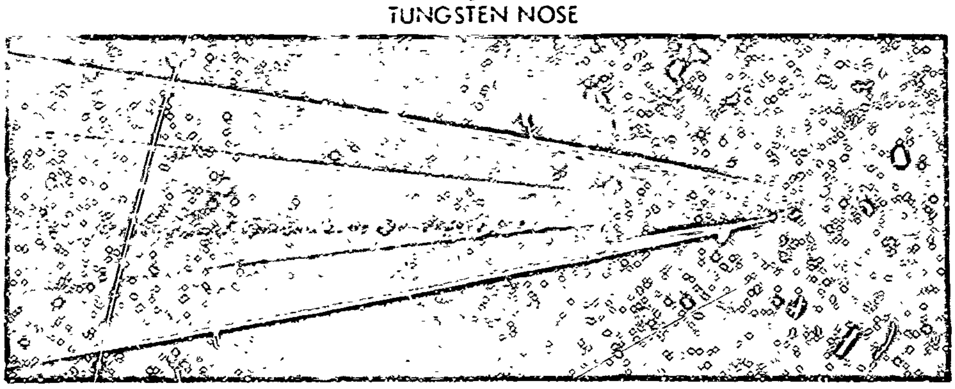


(b) SHOT NO. 4732, STATION 27V

$R_N / R_B = 0.027$, $M = 9.080$

$P = 1$ ATM, $R_{e_\ell} = 9.196 \times 10^6$

TUNGSTEN NOSE



(c) SHOT NO. 4727, STATION 9V

$R_N / R_B = 0.297$, $M = 7.586$

$P = 1$ ATM, $R_{e_\ell} = 3.013 \times 10^6$

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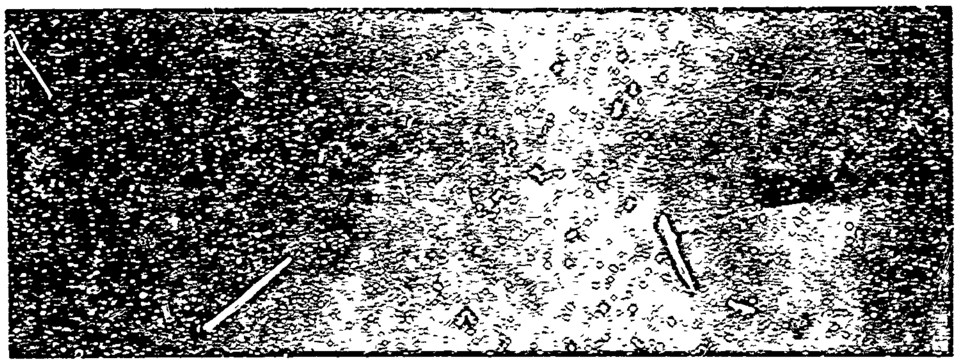
FIG. 7 CONTINUED

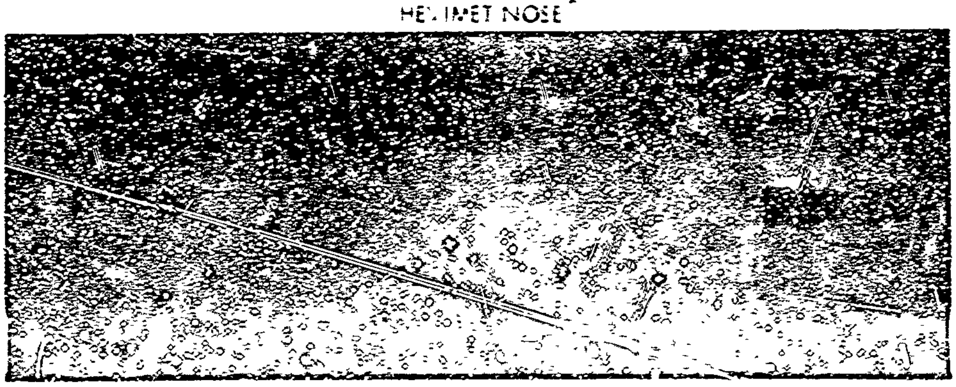


(d) SHOT NO. 4538 STATION 20[illegible]

0.002" NOSE FLAT DIA., M [illegible].20

P [illegible] 76.4 mm Hg, R_{e_ℓ} [illegible] 0.[illegible]5 × 10[illegible]

HEVIMET NOSE

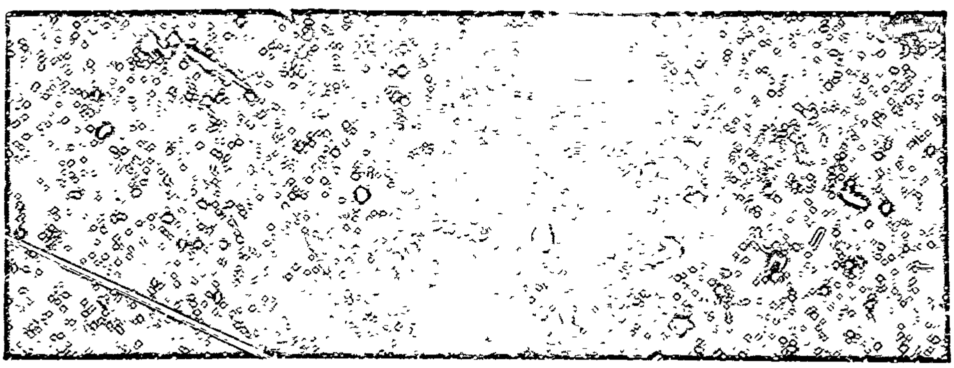


(e) SHOT NO. 44[illegible] STATION [illegible]V

R_N R_B = 0.02[illegible] M [illegible].[illegible]4

P [illegible]6.2 mm Hg, R_{e_ℓ} [illegible] 0.[illegible]77 × 10[illegible]

HEVIMET NOSE



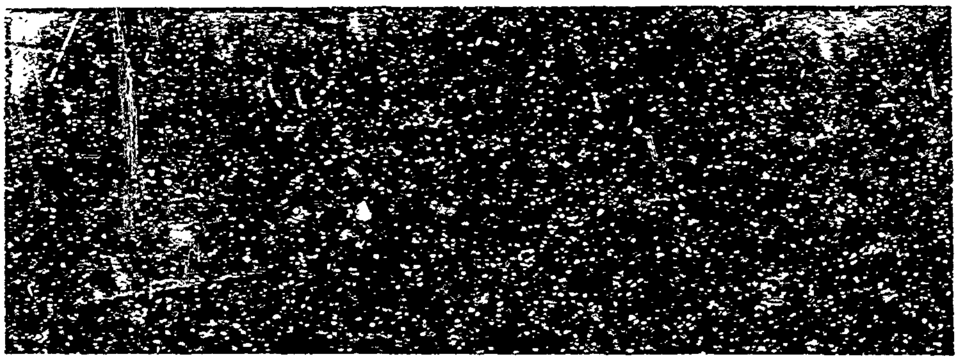
(f) SHOT NO. 4[illegible] STATION [illegible]

R_N R_B [illegible] 0.2[illegible] M [illegible]

P [illegible] 46.[illegible] mm Hg, R_{e_ℓ} [illegible] 0.24[illegible] × 10[illegible]

HEVIMET NOSE

FIG. [illegible] CONTINUED



(g) SHOT NO. 4742, STATION 13V

$R_N / R_B = 0.297$, $M = 8.244$

$P = 1$ ATM, $R_{e_\ell} = 3.354 \times 10^6$

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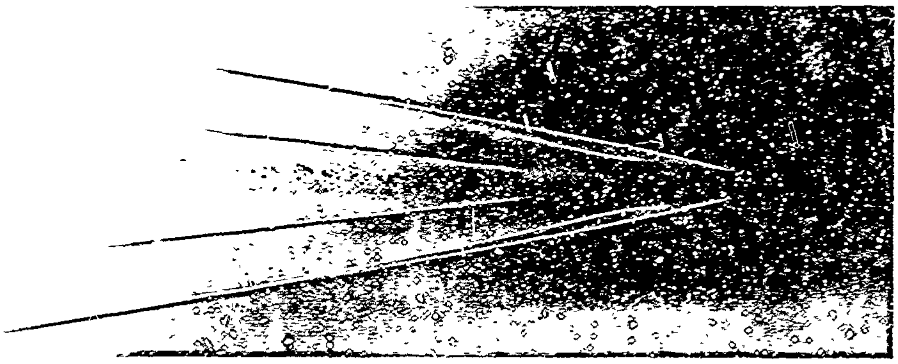

(h) SHOT NO. 4723, STATION 16V

$R_N / R_B = 0.297$, $M = 7.630$

$P = 1$ ATM, $R_{e_\ell} = 3.181 \times 10^6$

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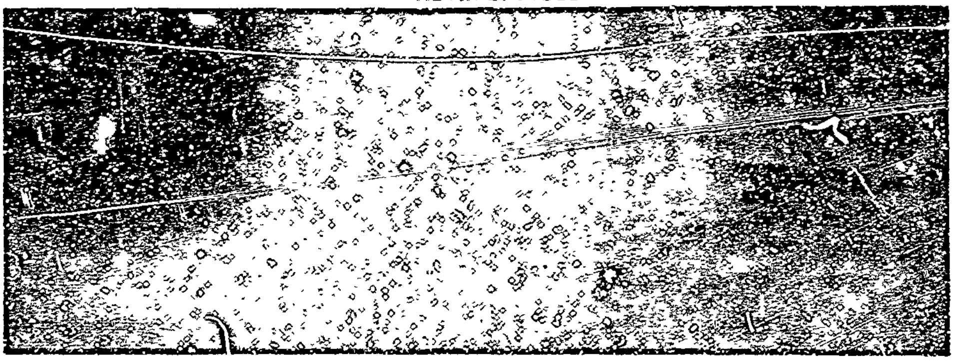

(i) SHOT NO. 4402, STATION 21V

$R_N / R_B = 0.027$, $M = 9.198$

$P = 37.7$ mm Hg, $R_{e_\ell} = 0.255 \times 10^6$

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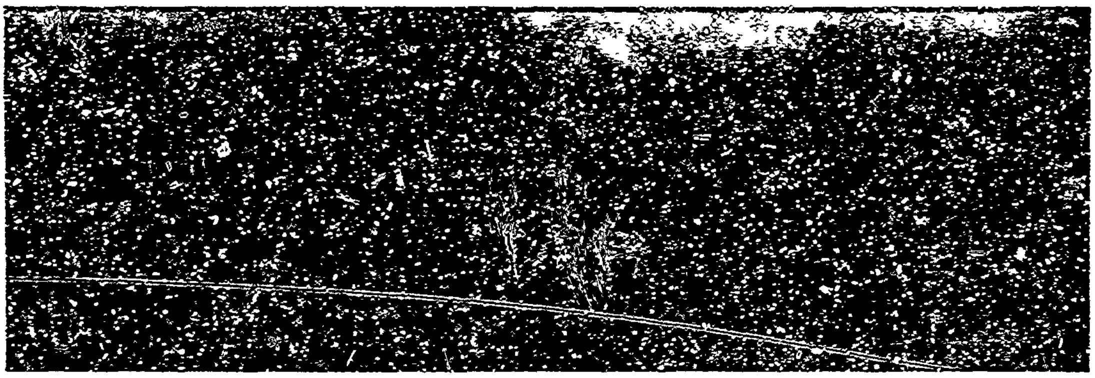
FIG. 7 CONTINUED



(j) SHOT NO. 4390, STATION 24V

$R_N / R_B = 0.297$, $M = 9.123$

$P = 75.5$ mm Hg, $R_{e_\ell} = 0.372 \times 10^6$

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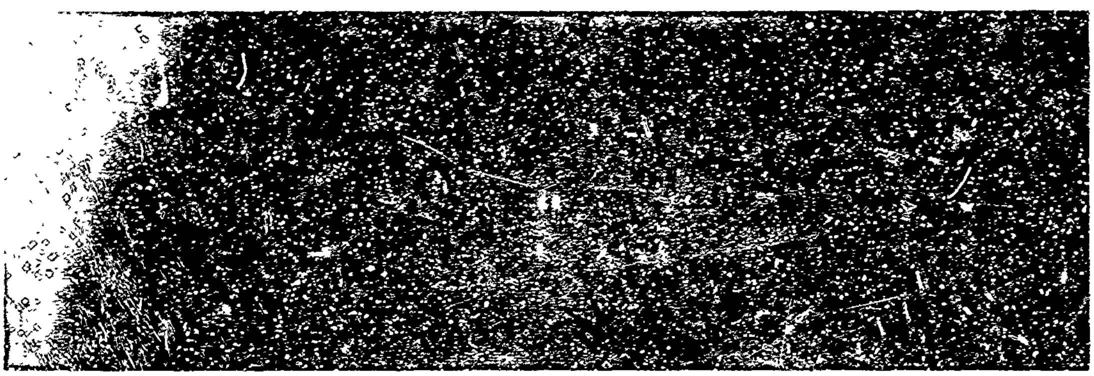

(k) SHOT NO. 4397, STATION 7V

0.002" NOSE FLAT DIA., $M = 8.226$

$P = 98.5$ mm Hg, $R_{e_\ell} = 0.605 \times 10^6$

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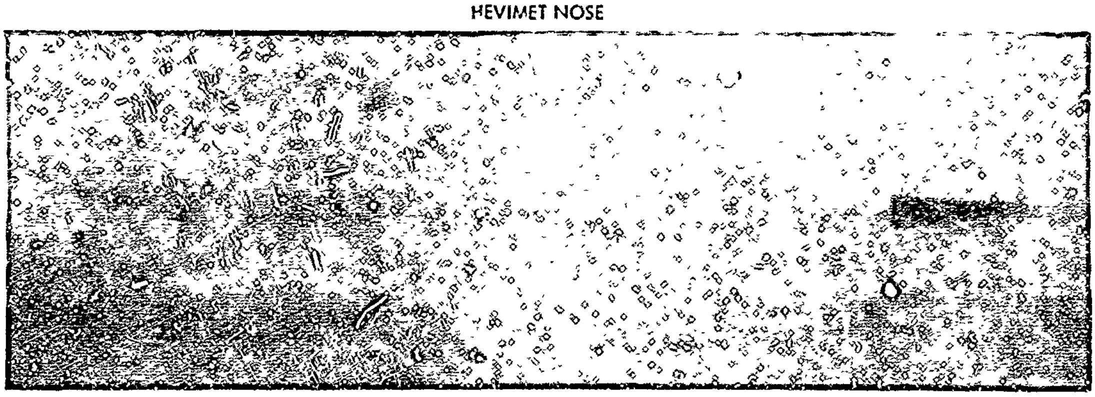

(l) SHOT NO. 4389, STATION 11V

$R_N / R_B = 0.297$, $M = 9.219$

$P = 91.0$ mm Hg, $R_{e_\ell} = 0.453 \times 10^6$

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FIG. 7 CONTINUED

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13. ABSTRACT

Drag and stability data obtained from hypersonic firings of both pointed and blunt nosed 12-degree 40-minute total-angle cones at several range pressures are tabulated. The drag coefficient of both cones decreased with an increase in the Reynolds number. No effect of Reynolds number on the center of pressure of either cone configuration was observed.

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